SHOCK-WAVE DYNAMICS UNDER EXPANSION OF THE SPARK CHANNEL IN GAS

K.V. Korytchenko, Yu.Ya. Volkolupov[1], M.A. Krasnogolovets[1], M.A. Ostrizhnoy[1], V.I. Chumakov[1], T.A. Semenets[1]

Kharkov Military University, Kharkov, Ukraine

[1] Kharkov National University of Radioelectronics, Kharkov, Ukraine

The process of formation of shock waves arising at a spark discharge is considered. According to analysis of experimental statistics the results of the various authors about dynamics of development of the spark channel are exposed to a doubt. The definition of a concept of time of formation of a shock wave is offered and its quantitative evaluation is carried out. It has allowed to distinguish the process of formation from the process of development of a shock wave, and also to explain the fact of formation of several shock waves at a spark discharge. The offered work can be put in a basis of a technique for evaluation of the intensity of a shock wave formed at a spark discharge.

PACS numbers: 52.35.Tc, 52.90.+z

During study of a possibility of realization of a detonation in the air by immediate initiation of a fuel mixture, the shock wave, which is formed at an electrical discharge detected qualitatively other character of dynamics of expansion of the spark channel.

It is known that the current of the high densities is accompanied by the concentrated emission of Joule heat. It leads to force heating of plasma, its thermalization, probably, to the further growth of ionization already by a thermal way. The fast raise of the gas temperature not compensated so fast warmly by a tap, reduces in a sharp raise of pressure in the current channel. The cylindrical shock wave is appeared. The first amplitude of a shock wave is supposed to be so great, that the temperature behind front is sufficient for thermal ionization of gas. Thus the boundary of the current channel is almost inseparable from the front of a shock wave. But soon, with deviation from the axes, the shock wave weakens, ceases to ionize gas and comes off the slower extending boundary highly of ionized area – spark channel. The channel extends now owing to a radial dispersion of gas enlarged by a shock wave, and operation of a thermal conduction.

In Fig. 1, 2 the shock waves are reduced, the radiant of which are the spark discharges [1]. As it is seen from these photos, during a spark discharge some shock waves are formed. Besides it is necessary, that the temperature in the channel can reach 20000K [2]. If the last value corresponds to translation temperature, then the shock wave should be formed at a normal density of an air and atmospheric pressure with an abrupt change of pressure in front no less than 180 atm. In turn, it would mean, that by a spark discharge it would be possible immediately to initiate a detonation of fuel mixtures at normal conditions. For example, for initiation of propane–oxygen mixture one needs a shock wave in these conditions with an abrupt change in front of the order of 100 atm. Practically to realize the latter it was not possible at atmospheric pressure, that basically differs from results obtained in early works [3, 4].

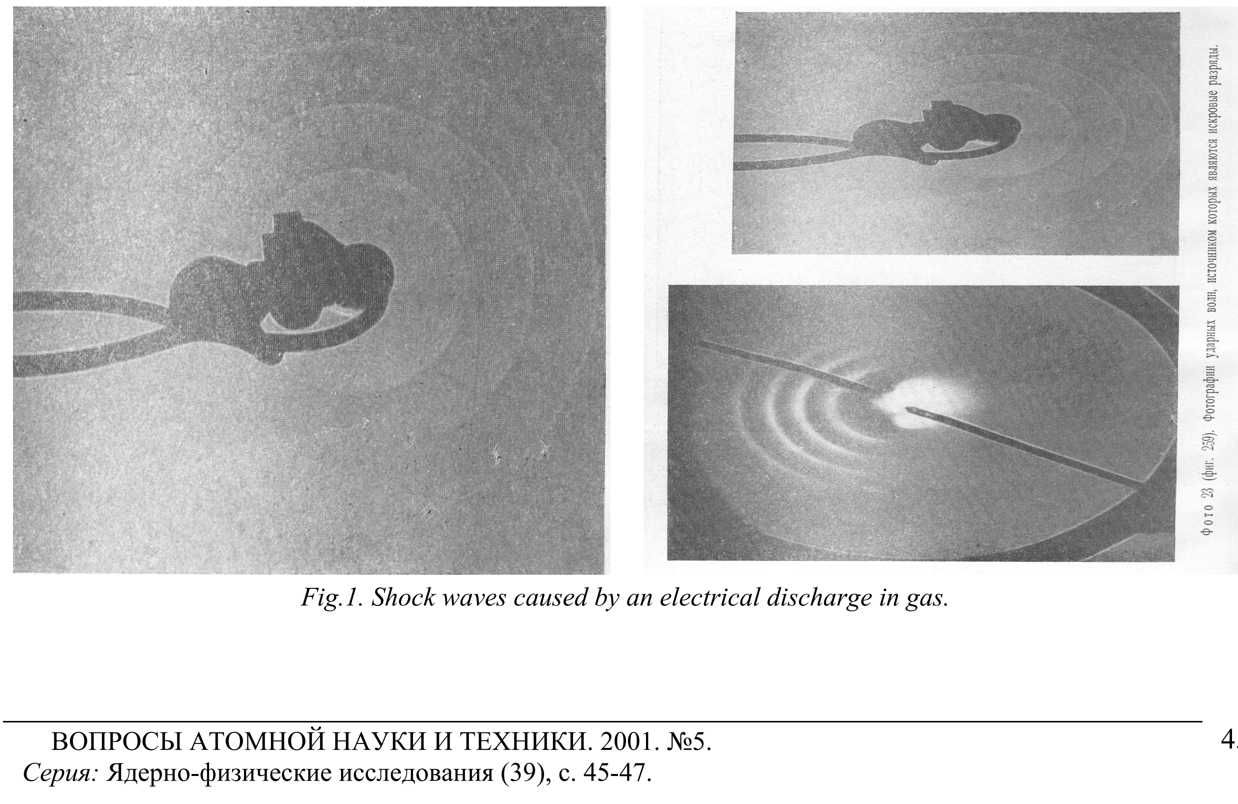

Fig.1. Shock waves caused by an electrical discharge in gas.

It is known that the initial energy of spark discharge distribution has a nonequilibrium character as on the degree of freedoms in gas in whole, and between gas molecules on excitation levels of degree of freedoms. In turn, each of processes has own characteristic time of equilibrium steadying. A part of the discharge energy is spent for ionization and dissociation of gas molecules with appropriate, from time-to-time, recombinations. Besides dynamics of an electric discharge immediately influences a character of energy distribution in gas (how it happens, is described below). As a radiant of shaping a shock wave is the translation energy of gas molecules it is important to carry out the analysis of all factors influencing the pumping velocity of this aspect of an energy.

To begin it is necessary to determine the time of shaping a shock wave. There are experimental and theoretical works devoted to study of a stage of initial expansion of the spark channel [1]. Though the judgements of the various authors concerning the process of expansion of the channel will not be coordinated among themselves, it is possible to consider as established, that in the beginning of a current flow the fast expansion of channels takes place with a velocity of the order of gas molecules thermal velocity. At the later stage of its development the spark channel extends considerably slower. The shock wave velocity as a function of the distance to a center of the spark channel constructed by Folye data is shown in Fig. 2.

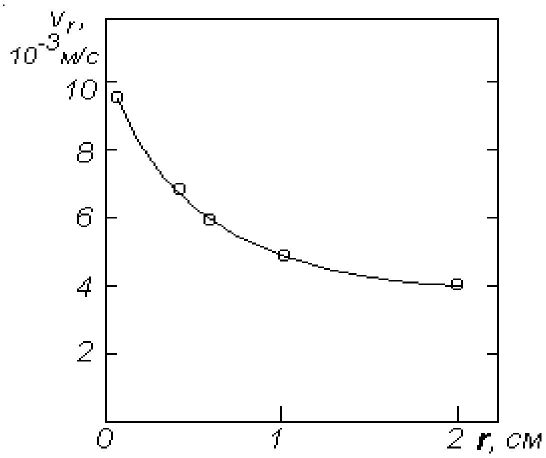

Fig. 2. The velocity of shock wave v_r versus the distance r from the center of the spark channel.

Explanation of a concept of the shock wave formation time allows to remove incompatibilities in the judgements of the various authors. The shock wave formation time is a phase of time, during which the thermodynamic equilibrium on translation degree of freedoms in a locally heated volume of gas (spark channel) would be established, if it was in limited volume. In a real discharge is actually formed such thermodynamic distribution of parameters, which corresponds to a solution of a task about force explosion.

Distribution of densities and temperatures for a self-similar solution in dimensionless magnitudes are reduced in Fig. 3, 4 [5]. The shock wave formation time τ_{sw} is of the order of average time between gas-kinetic collisions in gas τ_{gk} :

$$\tau_{sw} \approx \tau_{gk} = l / v, \quad (1)$$

where l is the average gas-kinetic track length; v is the average velocity of molecules of gas.

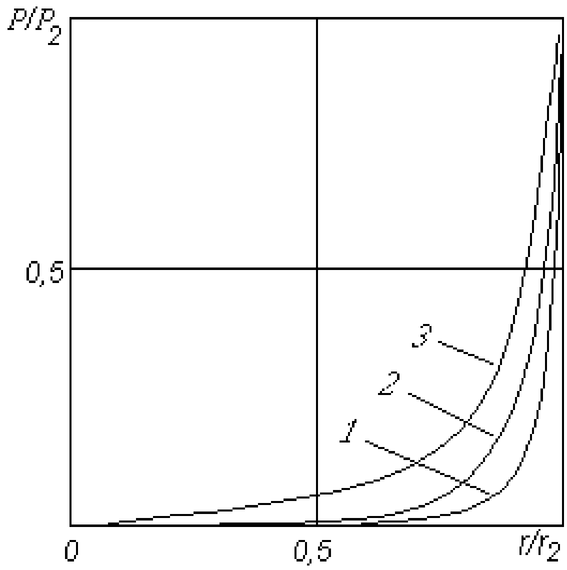

Fig. 2. Distribution of density behind a shock wave at γ = 1, 4.

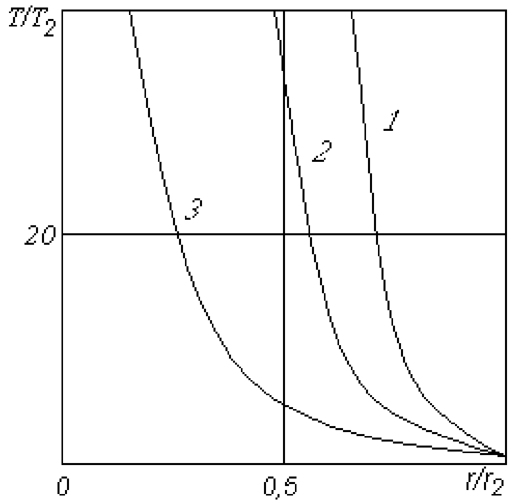

Fig. 3. Distribution of temperature behind a shock wave at γ = 1,4: 1 - spherical case; 2 – cylindrical case, 3 – flat case.

It is explained that during a shock wave formation all molecules which were in locally heated volume of gas simultaneously participated.

The table with the calculated values of relaxation time for various processes is shown below [1]. Dynamics of shock wave development proceeds with the velocity that is not exceeding a sound velocity of heated medium. Therefore the shock wave velocity distribution as a minimum by an order is lower than a velocity of its formation. It explains inconsistencies in data obtained by the various authors.

The shock wave formation time shown in Table 1 is no less then 10^{-4} s with the pressure p = 1 atm. With growth of a volumetrical power density of discharge energy releasing the shock wave formation time is reduced, as the faster growth of temperature in the channel takes place.

Table 1. The calculated values of relaxation time for various processes with p = 1atm.

Process	$\Delta\tau$, s
Maxwell velocity of electrons distribution	10^{-13}
Ionization	10^{-12}
Transmission of an energy from electrons to atoms	$10^{-5} – 10^{-6}$
Maxwell velocity of atoms distribution	$10^{-8} – 10^{-10}$

The latter means magnification of an average velocity of molecules at preservation of average gas-kinetic track length that calls a reduction of time of a translation relaxation (following from expression 1).

Practically all electrical discharges have a duration exceeding the shock wave formation time, therefore further dynamics of development of a shock wave is determined by a relation between an energy release velocity in the spark channel and velocity of a decrease of a volumetric density of an energy in an outcome of distribution of a shock wave.

The offered work can be put in a basis of a technique of an evaluation of shock wave intensity formed at a spark discharge. It will allow to estimate safety of application of electrical devices in easy detonated fuel mixtures.

REFERENCES

1. J.Mick, J.Krags. *Electric breakdown in gases*. Moscow: Izdatel'stvo inostrannoj literatury, 1960. p. 76, 472-474 (in Rusian).
2. Yu.P.Raizer. *Physics of the gas discharge*. Moscow: Nauka, 1987. p. 476.
3. S.I.Drabkina // *Zhournal Ehksperimental'noj i Tekhnicheskoj Fiziki*. 1951, v. 21, p. 473 (in Russian).
4. S.I.Braginsky // *Zhournal Ehksperimental'noj i Tekhnicheskoj Fiziki*. 1958, v. 34, p. 1548 (in Russian).
5. L.I.Sedov. *Methods of similarity and dimensionality in mechanics*. Moscow: Nauka, 1977. p. 257-258.